Astro 191 - Space Astrophysics

Dr. Mike Corcoran
301-286-5576
corcoran@barnegat.gsfc.nasa.gov

1. Course Overview
    - structure
    - instructors
    - lectures
    - requirements - exams, problem sets, presentations, field trip
    - contact

2. X-ray and Gamma-Ray physics
    - objects
    - unique evidence

3. Comparison of High Energy and Optical Astronomy

4. Brief History of High-Energy Astronomy from Space
    - X-ray missions
    - Gamma-Ray missions

5. Future Steps

Astro 191 - Space Astrophysics	Dr. Mike Corcoran 301-286-5576 corcoran@barnegat.gsfc.nasa.gov

1. Course Overview

- structure: 2 lectures per week (T-Th, 6:10-7:25pm) on various topics dealing with aspects of astrophysics as determined mainly from observations of high-energy radiation (X-ray and Gamma-Ray)

- TEXT: “Exploring the X-ray Universe” by Phil Charles and Fred Seward

- Instructors: lectures will be given by a group of 6 astronomers from the GSFC LHEA and Universities Space Research Association (USRA)
  - — Dr. Eric Christian
  - — Dr. Mike Corcoran
  - — Dr. Koji Mukai
  - — Dr. Ilana Harrus
  - — Dr. Tahir Yaqoob
  - — Dr. Paul Nandra

- Course Requirements: **Problem Sets** (50% of grade; due 1 week after they are handed out); 1 **Midterm** (25%); **Final** (25%); 1 presentation (**Grad Student only**); 1 **field trip** to GSFC

- Contact
  http://lheawww.gsfc.nasa.gov/docs/outreach/GWU_Space_Astrophysics/
  - — via e-mail `gwu_usra@olegacy.gsfc.nasa.gov`
  - — phone numbers via finger:
    `% finger first_name.last_name@gsfc.gsfc.nasa.gov`
  - — Office hours: by appointment

Astro 191 - Space Astrophysics

Dr. Mike Corcoran
301-286-5576
corcoran@barnegat.gsfc.nasa.gov

2. X-ray and Gamma-Ray Physics

a) X-ray properties:

— Discovered 1895 by Wilhelm Conrad Rontgen via experiments with vacuum tubes (Crookes Tube)

— The X-ray band in the EM spectrum corresponds roughly to wavelengths in the range 0.01-10 nanometers (nm); (visible light: 400-800 nm)

— typically X-ray astronomers refer to the energy, not the wavelength, of an X-ray photon. The energy range of the X-ray band is about 0.1-100 kilo-electron Volts (keV), where

1 eV = 1.6E-19 Joules
An X-ray photon with energy 1 keV corresponds to a photon of wavelength 1.26 nm

b) Gamma-Ray properties:

— photons with energies which are beyond X-ray energies (i.e. E > 100 keV, or wavelengths shorter than about 0.01 nm)

— typically energies: keV, MeV and GeV (now TeV too)

Astro 191 - Space Astrophysics

Dr. Mike Corcoran
301-286-5576
corcoran@barnegat.gsfc.nasa.gov

2c) Physical processes which generate X-rays and/or Gamma Rays

i. thermal processes:
- — Continuum: free-free emission (bremstrahlung from rapid motions of electrons & ions in an ionized plasma)
- — Line Emission: additional K-shell & L-shell line emission if plasma not fully ionized

Extremely high temperatures required:

Wien's law:

$$\lambda_{max}\, T = 0.29 \text{ cm K}$$

if $\lambda max < 10$ nm,
then $T > 300{,}000$ K

i.e. $T > 10^5$ K to generate X-ray emission;

$T > 10^9$ K for soft gamma rays

(*What are the heating processes*?)

Astro 191 - Space Astrophysics

Dr. Mike Corcoran
301-286-5576
corcoran@barnegat.gsfc.nasa.gov

2c) Physical processes which generate X-rays and/or Gamma Rays

ii. non-thermal processes:

— Inverse Comptonization (energetic electron transfers energy to photon; photon is "up-scattered" (requires population of fast electrons + UVphoton source)

— synchrotron radiation: energetic, fast-moving electrons spiralling around magnetic lines of force (requires population of fast electrons and strong magnetic fields)

— isotopic decay (requires significant amounts of radioactive isotopes with suitably short half life)

— matter/anti-matter collisions (annihilation lines)

(*What are the accelerating processes*? *What is the source of the B field*? *What produces the radioactive isotopes*? *What is the source of the antimatter*?)

Astro 191 - Space Astrophysics

Dr. Mike Corcoran
301-286-5576
corcoran@barnegat.gsfc.nasa.gov

2d) High Energy Astrophysics: Physics of Extreme Objects and Phenomena

- stellar deaths: *supernovae, novae, white dwarfs, neutron stars, black holes*
- stellar heating: *stellar flares, stellar ejections*
- macroscopic cosmic physics:
  - *supermassive black holes;*
  - *motions of galaxies and clusters;*
  - *cluster potential wells*

Astro 191 - Space Astrophysics

Dr. Mike Corcoran
301-286-5576
corcoran@barnegat.gsfc.nasa.gov

3. Comparison Between Optical and High Energy Astronomy:

Optical Astronomy	High Energy Astronomy
• Atmosphere transparent	• Atmosphere **opaque**
• ground &/or space observatories	• space &/or high altitude observatories (balloons)
• weather impacts observations	• weather not an issue (but “space weather” is)
• diurnal cycle	• orbital cycle
• visibility depends on observer’s latitude	• visibility depends on spacecraft altitude
• good resolution requires large collecting area (sub-arcsec)	• in theory resolution good but in practice not (*Chandra* best resolution ~ arcsec)
• Imaging: refraction, reflection, interferometry	•Imaging: reflection
• detectors: CCDs, photographs	• detectors: CCDs, proportional counters, & non-imaging
• Science: spatial, spectral, motions	• Science: spatial, spectral, motions

Dr. Mike Corcoran
301-286-5576
corcoran@barnegat.gsfc.nasa.gov

4. Brief History of High-Energy Astrophysics

a) X-ray Astrophysics

`http://imagine.gsfc.nasa.gov/docs/introduction/xray_information.html`

- Began in the early 1960's with rocket flights (basically geiger counters with collimators to restrict field of view to a few degrees).

- **1962**: First successful detection of a cosmic X-ray source by a group at American Science and Engineering (AS&E). (Riccardo Giacconi, Herb Gursky, Frank Paolini, and Bruno Rossi et al). First source found in Scorpius, named "Scorpius X-1" ("**Sco X-1**")

- Discovery of Sco-X1 prompted other attempts: such as

  — ***Uhuru*** (Dec '70- Mar '73) - first earth-orbiting mission dedicated entirely to celestial X-ray astronomy. 2 sets of proportional counters sensitive to ~ 2-20 keV X-rays. Surveyed entire sky ("1U catalog" --> "4U catalog")

  — ***Ariel 5*** ('74-'80). Multiple instruments to provide arcmin spatial positions, X-ray spectrometers, X-ray polarimeters ("pointed instruments"); also 2 all sky instruments

  — ***SAS-3*** ('75-'79) - arcsecond X-ray source positions & search for transient phenomena

  — ***OSO-8*** ('75 -'78) - X-ray spectra, hard X-ray observations, diffuse emission

  — ***HEAO-1*** ('77-'79) - mapped X-ray sky

Dr. Mike Corcoran
301-286-5576
corcoran@barnegat.gsfc.nasa.gov

4a) X-ray Astrophysics

• Modern era: began with ***HEAO-2*** (***EINSTEIN***) X-ray Observatory

— First fully **imaging** X-ray telescope put into space, with angular resolution of a few arcmin—arcseconds, a field-of-view of tens of arcminutes, and a sensitivity ~1000 times greater than any previous mission

— Detectors:
– Imaging Proportional Counter (IPC) - arcmin spatial resolution, X-ray spectral capabilities
– High Resolution Imager (HRI) - microchannel plate detector, arcsec spatial resolution

— Results: revealed ubiquity of x-ray emission, (with curious "lapses") source identifications

• **Current Missions**

— ***ROSAT*** ('90-'98): similar to *EINSTEIN* with better mirrors and detectors; extended coverage to soft X-ray band; 1st all sky X-ray imaging survey

— ***ASCA*** ('93-00): imaging at E > 4 keV; 1st orbital flight of an X-ray CCD; Best X-ray spectral resolution of any mission yet flown.

— ***RXTE*** ('95-): large area proportional counter, very high time resolution; source monitoring

— ***BeppoSAX*** ('96-?) capable of nearly simultaneous X-ray and Gamma-ray observations

• ***CHANDRA Advanced X-ray Facility*** ('99-?): will provide best spatial and spectral resolution of any X-ray observatory (CCD detectors)

•***XMM*** ('99-?) best combination of sensitivity, spectral and spatial resolution, plus simultaneous optical data (CCD detectors

XMM ('99-?) best combination of sensitivity, spectral and spatial resolution, plus simultaneous optical data (CCD detectors

Astro 191 - Space Astrophysics

Dr. Mike Corcoran
301-286-5576
corcoran@barnegat.gsfc.nasa.gov

4b) Gamma-Ray Astrophysics

`http://imagine.gsfc.nasa.gov/docs/science/know_l2/history_gamma.html`

- First in-orbit gamma-ray telescope on the ***Explorer-XI*** satellite (1961), detected **< 100 cosmic gamma-ray photons**, appearing to come from all directions in the Universe; a diffuse background rather and an identified source

- First significant detection of cosmic gamma-radiation (**621 photons**) by ***OSO-3*** (1967) - suggested concentration of gamma rays along the galactic equator

- ***SAS-2*** ('72-'73): clearly established a high energy (> 35 MeV) component to the diffuse celestial radiation. High-energy gamma-ray emission was also seen from discrete sources such as the Crab and Vela pulsars.

- ***COS-B*** ('75-'82): Study the spectrum and distribution of galactic gamma rays, study new and previously detected point sources, determine flux & distribution of extragalactic gamma rays.

- ***Vela*** satellite series (60's - 70's): designed to detect gamma-ray flashes from nuclear tests, instead discovered cosmic gamma-ray "bursts".

- ***COMPTON GAMMA RAY OBSERVATORY*** (CGRO, '91-?) all sky monitor; transient events, all sky maps, studies of point sources. Showed that bursts were NOT aligned with the galactic plane (and ruled out the most generally accepted burst model)

- ***BeppoSAX*** ('95-): wide field gamma ray and narrow field X-ray instruments; provided 1st image of an "X-ray afterglow" of a gamma ray burst with arcsec source location

Astro 191 - Space Astrophysics

Dr. Mike Corcoran
301-286-5576
corcoran@barnegat.gsfc.nasa.gov

5. Future Missions

a) X-ray

- ***ASTRO-E*** (?) - follow on to ASCA, will provide imaging, high-resolution spectra using calorimeters, launch Feb 8 2000.

- ***Constellation-X*** (2007–?) - fleet of 6 identical satellites will provide order of magnitude sensitivity and resolution increase in the 0.2-40 keV band

b) Future Gamma-Ray Missions

- ***High Energy Transient Explorer (HETE-2)*** (1999-?): provides arcsecond positions of GRBs

- ***International Gamma-Ray Astrophysics Laboratory (INTEGRAL)*** (2001-?) spectroscopy, positions and simultaneous X-ray and optical observations of Gamma-ray sources

- ***Gamma-Ray Large Area Space Telescope (GLAST)*** (2005–?) - high-sensitivity imaging and spectral observations in the 10 MeV–100 GeV band

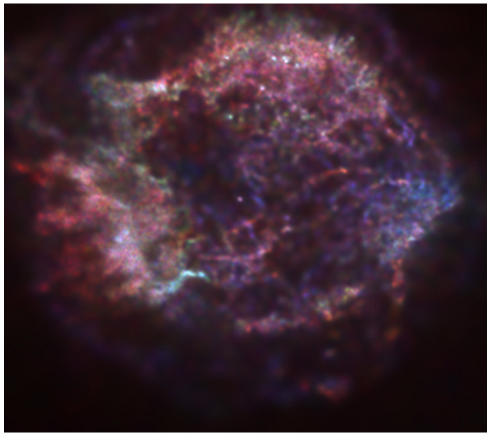
Astro 191 - Space Astrophysics

Dr. Mike Corcoran
301-286-5576
corcoran@barnegat.gsfc.nasa.gov

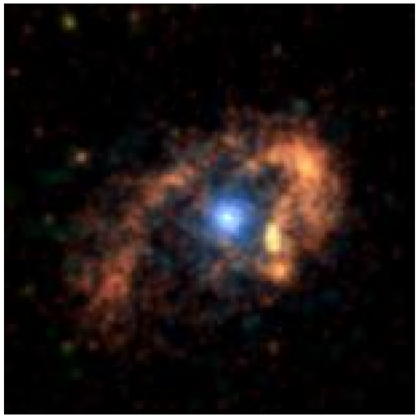
The Chandra X-ray Observatory

Instruments:
Advanced Camera for Imaging Spectroscopy (ACIS),
High Resolution Camera (HRC),
Low, Medium and High Energy Transmission Gratings

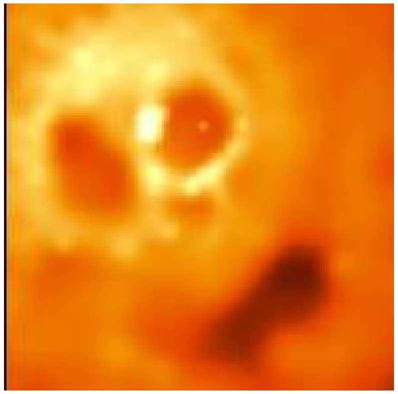
Launch: Jul 1999



Finding a neutron star in the Cas A supernova remnant



X-rays from the extremely massive star Eta Carinae



X-ray image of the Perseus cluster of galaxies

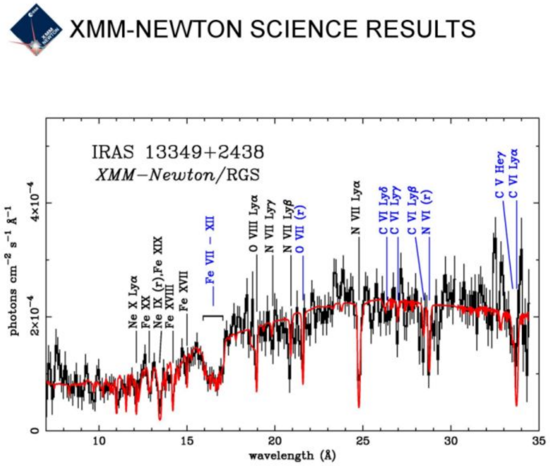
Dr. Mike Corcoran
301-286-5576
corcoran@barnegat.gsfc.nasa.gov

XMM

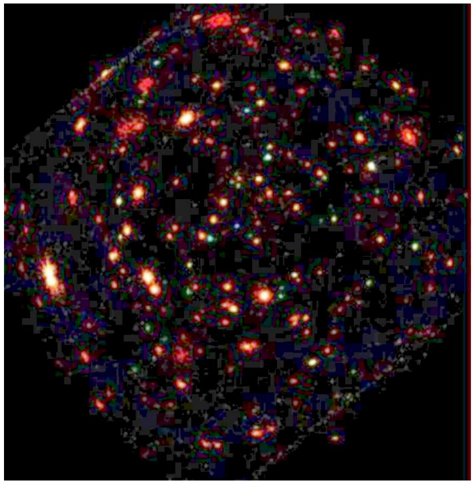
Instruments:
European Photon Imaging Camera (EPIC)
Reflection Grating Spectrometer (RGS)
Optical Monitor (OM)

Launch: Dec 1999

The most distant x-ray source ever seen



X-ray absorption around a supermassive black hole



The “Lockman Hole” in X-rays

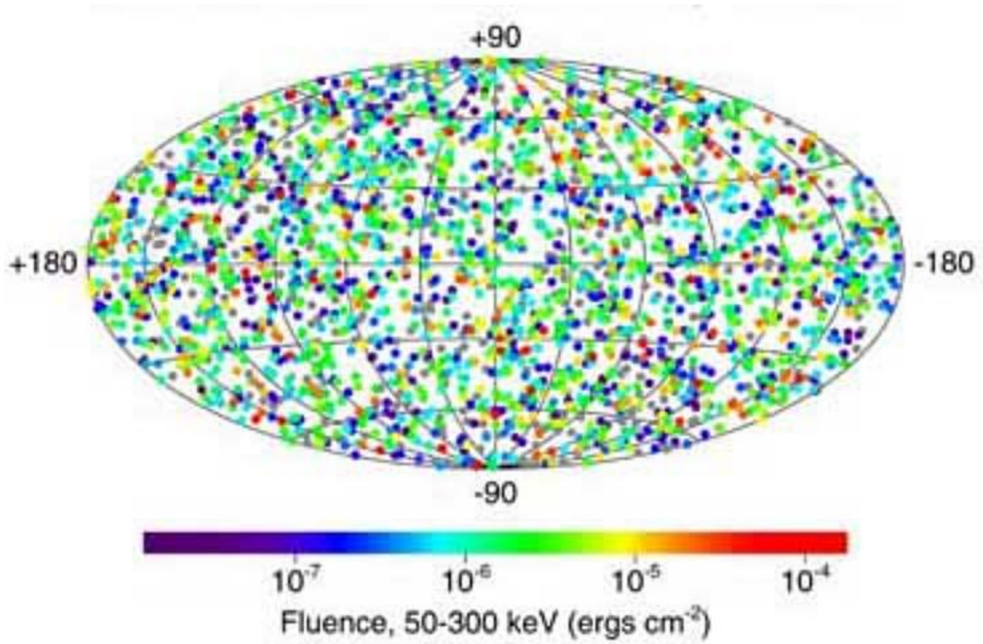
Astro 191 - Space Astrophysics

Dr. Mike Corcoran
301-286-5576
corcoran@barnegat.gsfc.nasa.gov

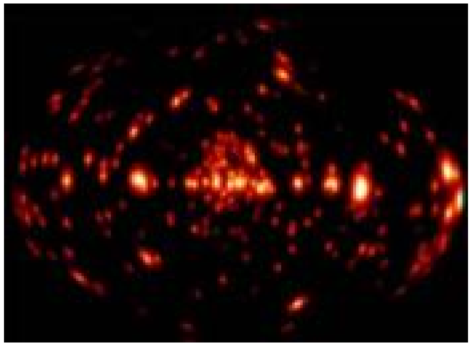
The Compton Gamma Ray Observatory

Instruments:
Burst and Transient Source Experiment (BATSE)
Imaging Compton Telescope (COMPTEL)
Oriented Scintillation Spectrometer Experiment (OSSE)
Energetic Gamma-Ray Experiment Telescope (EGRET)

Launch: Apr 1991



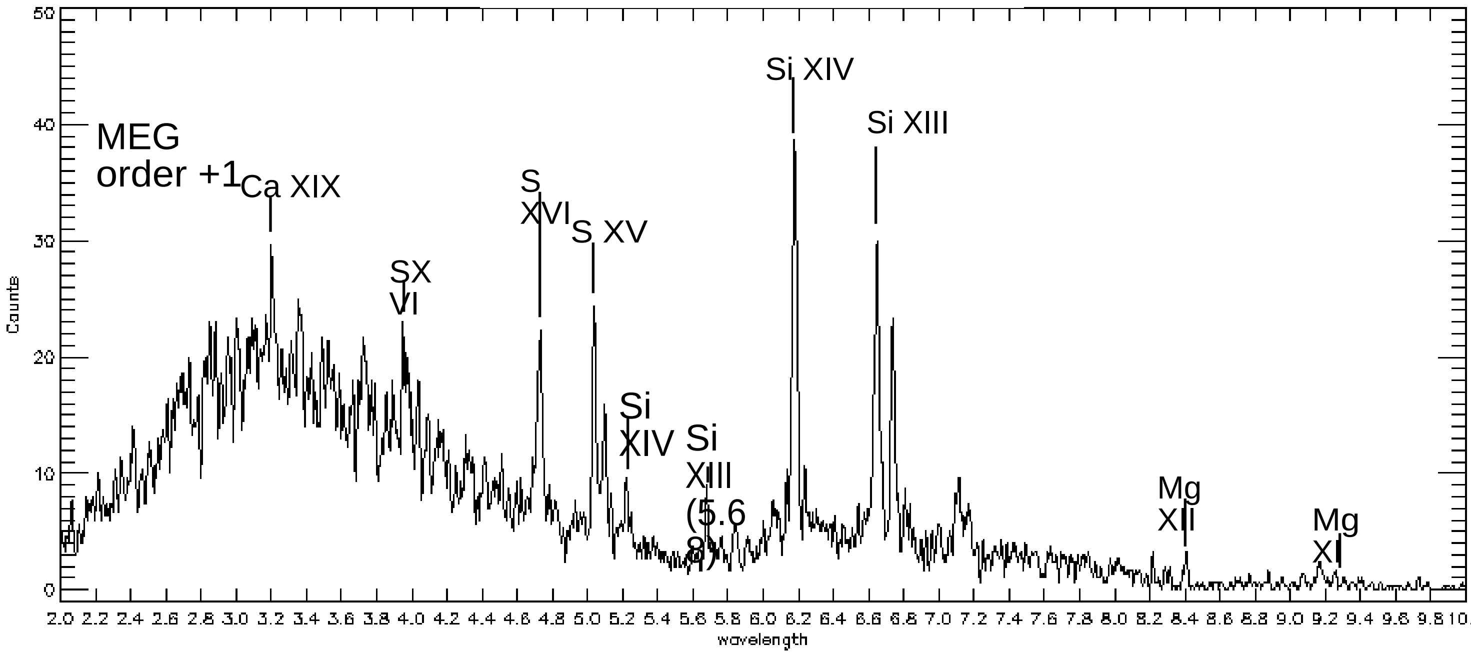
Gamma Ray Burst Map from BATSE



EGRET point source map

Astro 191 - Space Astrophysics

Dr. Mike Corcoran
301-286-5576
corcoran@barnegat.gsfc.nasa.gov



Modern X-ray Spectrum (Eta Carinae from Chandra High Energy Transmission Grating